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**FATIGUE TESTING OF A FLOOR ANCHOR SPECIMEN**

by

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## FATIGUE TESTING OF A FLOOR ANCHOR SPECIMEN

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*The fatigue testing of a floor anchor restrained in concrete is outlined. Aspects of the test and fatigue life are discussed.*



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## 1. INTRODUCTION

To expand its capabilities and services, Aircraft Structures Division at the Aeronautical Research Laboratory (ARL) Defence Science and Technology Organisation, has constructed a new Structural Test Laboratory (STL) (Fig. 1).

The strong floor slab (Fig. 2) located in the STL incorporates screw-threaded socket anchors (Figs. 3-5) used to restrain static and dynamic loads from test rigs. Threaded studs can be screwed into the sockets and used to clamp rig members to the floor.

The design specification for the building called for a minimum life of  $10^9$  cycles for each anchor to a maximum tensile load of 10 000 kg force (98 000 N).

Some available data [1,2] for large diameter threaded specimens comparable to the STL floor anchors, indicated that the anchor may not meet the design specification for fatigue life. Those data typically showed fatigue lives of the order of  $10^7$  cycles at alternating stress amplitudes approximately half that specified for the STL floor anchors, but at significantly higher mean stresses (Appendix A). In order to resolve the doubt on the STL floor anchor design cast by the data in References 1 and 2, a fatigue test was conducted on a specimen representative of a 'cast-in' floor anchor.

This paper describes the construction of the specimen and its associated testing up to  $10^8$  cycles.

## 2. TEST SPECIMEN

The arrangement of the anchors in the strong floor slab is shown in Figure 4. Typical spacing of anchors is 1000 mm. Details of the cast-in anchor are shown in Figure 5. It comprises an internally threaded socket 170mm long, which finishes flush with the surface of the floor. An anchor rod, 900mm long, is screwed into the bottom 50mm of the socket and penetrates through to the bottom of the 1m thick slab. The stud to anchor rig members then screw into the top 90mm of the socket. All components are of galvanised mild steel and a 36mm metric thread size is used throughout. The floor anchor is not connected to the slab reinforcement but relies on a flange near the base of the anchor rod to hold it in the concrete. The test specimen was fabricated from a spare anchor assembly and surplus materials used in the construction of the strong floor.

Figure 6 shows the floor anchor specimen assembly. To contain the anchor for this test, a mild steel casing was constructed (Fig. 7) into which the anchor and associated reinforcing bars were fitted (Fig. 8). Subsequently, concrete from the same

batch as the strong floor was poured into the specimen assembly. The enclosed area around the anchor was square in cross-section with a side length of 300 mm. The specimen size was limited to a manageable weight and for clearance in the testing machine. The specimen was designed to locally represent the STL floor anchors, surrounding concrete and reinforcement as closely as possible. However, because of a late change to the design of the STL strong floor reinforcement, the reinforcement in the specimen was of lighter gauge but more closely spaced than in the strong floor. Y20 reinforcement rods at 100mm grid pitch were originally specified for the slab, but were changed to Y24 rods at 150mm pitch.

Machined fittings were used to mount the specimen in the testing machine. The general set up is shown in Figure 9.

### 3. TEST PROCEDURE

A closed-loop servo-controlled hydraulic machine (Appendix B) was used to apply the load cycles. For stability, the specimen was inverted and bolted to the cross-head of the machine (Fig. 10). A steel cable was attached to the casing and testing machine crosshead in order to support the specimen in the event of bolt failure. The load train from the specimen to the actuator was as follows (Fig. 9):

- (i) The anchor stud was connected via an adaptor to the load cell.
- (ii) The load cell was connected via an adaptor and a long slender rod to the actuator.

All links were appropriately secured with locking nuts.

The common universal testing configuration where the specimen is located between the actuator and load cell with universal joints to eliminate bending of the specimen was not adopted here. The joints involved would have incurred excessive pin wear and lubrication problems due to the large number of cycles required for testing. Instead, a long slender connecting rod was used at one end to minimise bending loads and care was taken with the mounting of the specimen to the machine crosshead to achieve good alignment. Because the loading was all tensile, potential buckling of the long load train was not a factor.

A servo-amplifier control system was programmed to produce a constant amplitude sinusoidal loading (0 to 98 kN).

On completion of the fatigue test a static tensile test was conducted to determine the strength of the stud and anchor. The floor anchor specimen was tested to failure in a 2MN MTS machine.

#### **4. RESULTS**

Visual inspections were carried out regularly during fatigue cycling in order to detect any deterioration of the specimen and load linkage.

Cycling commenced on the 1/9/87 and one hundred million cycles were completed by 17/10/90. The following is a record of events up until 100 000 000 cycles.

**At zero cycles:**

Cycling commenced.

**At 169 000 cycles:**

Daily inspections revealed no signs of deterioration. It was determined that 1000 cycles were completed in 6.5 minutes, giving a test frequency of 2.6 Hertz.

**At 1 136 000 cycles:**

A detailed inspection was undertaken. The load train was dismantled and a visual inspection of the stud connection was made. Lubricating grease was evident at the rim of the stud socket, this having accumulated under gravity due to the configuration of the specimen. No visible damage to the stud was observed. It was recommended that the test be continued until  $10^8$  cycles at the prescribed load, at which point a further detailed inspection would be made.

**At 2 211 000 cycles:**

Specks of concrete were collected in the retaining tray. An inspection revealed that a slight amount of concrete spalling was evident. This was not considered critical and testing was continued.

**At 4 195 000 cycles:**

The micro-switch displacement limits were exceeded due to adaptor bolt failure. A new bolt, fitted with spherical seat to improve alignment was used as a replacement and cycling was continued.

**At 7 312 000 cycles:**

Concrete started to chip away around the socket. The concrete chips were 5 to 10 mm long. No apparent damage to the stud was observed and testing continued.

**At 10,000,000 cycles:**

The load chain was dismantled and a detailed inspection of the stud-socket arrangement was made. At some stage after 10 000 000 cycles the stud-socket had separated locally from the concrete. No further damage was observed and testing continued up to  $10^8$  cycles.

#### **At 100 000 000 cycles:**

Fatigue testing was stopped. Visual inspection revealed no sign of failure or cracking. The static strengths of the stud and anchor were determined. In the first test the stud failed under a tensile load of 417.4kN and elongated by over 20mm. The failure occurred through the thread root just outside the end of the socket. The stud was then replaced with a high tensile steel stud and the test was repeated. This time the anchor rod failed just below the socket, and the socket and a short length of the anchor rod broke out of the concrete, causing significant spalling of the surrounding concrete and exposing the reinforcement rods (Fig. 11). Failure of the anchor rod was recorded at a tensile load of 502kN. The anchor rod elongated approximately 15mm. Both fractures are shown in Figure 12.

### **5. DISCUSSION**

The testing machine operating frequency limit of 2.6Hz meant that it would take a prohibitively long time (40 years) to test the specified life of  $10^9$  cycles. Testing to  $10^8$  cycles followed by a residual strength test was adopted as a compromise. It took just over 3 years to reach the  $10^8$  cycles at full amplitude.

In the residual strength testing, the anchor assembly exhibited good overload protection characteristics, in that the stud failed first. The stud is a removable and readily replaceable component.

### **6. CONCLUSIONS**

The testing to  $10^8$  cycles and subsequent residual strength testing has not satisfied the design specification for  $10^9$  cycles, but has demonstrated that the anchors should have adequate life for their general use in the STL. At the end of  $10^8$  cycles no signs of deterioration affecting the life of the anchor assembly were observed.

The 20% reserve strength of the anchor rod over the stud is a good feature and should be preserved. If high strength steel studs are used, they should be appropriately waisted down so that they fail at a tensile load of approximately 420kN.

### **7. ACKNOWLEDGEMENTS**

The author wishes to acknowledge the contributions made by K. Watters and the Technical officers and Assistants from the Structures Experiment and Instrumentation Groups of Aircraft Structures Division, ARL.



## REFERENCES

- [1] ESDU (Engineering Science Data Unit) 68045 *Fatigue strength of large screw threads under axial loading.*
- [2] Rowan, R.W., Beckett, R.C., Simpson, R., *Static and fatigue tests on prestressing steel bars and couplings.* Aeronautical Research Laboratories, Structures and Materials Technical Memorandum 125 (1963).

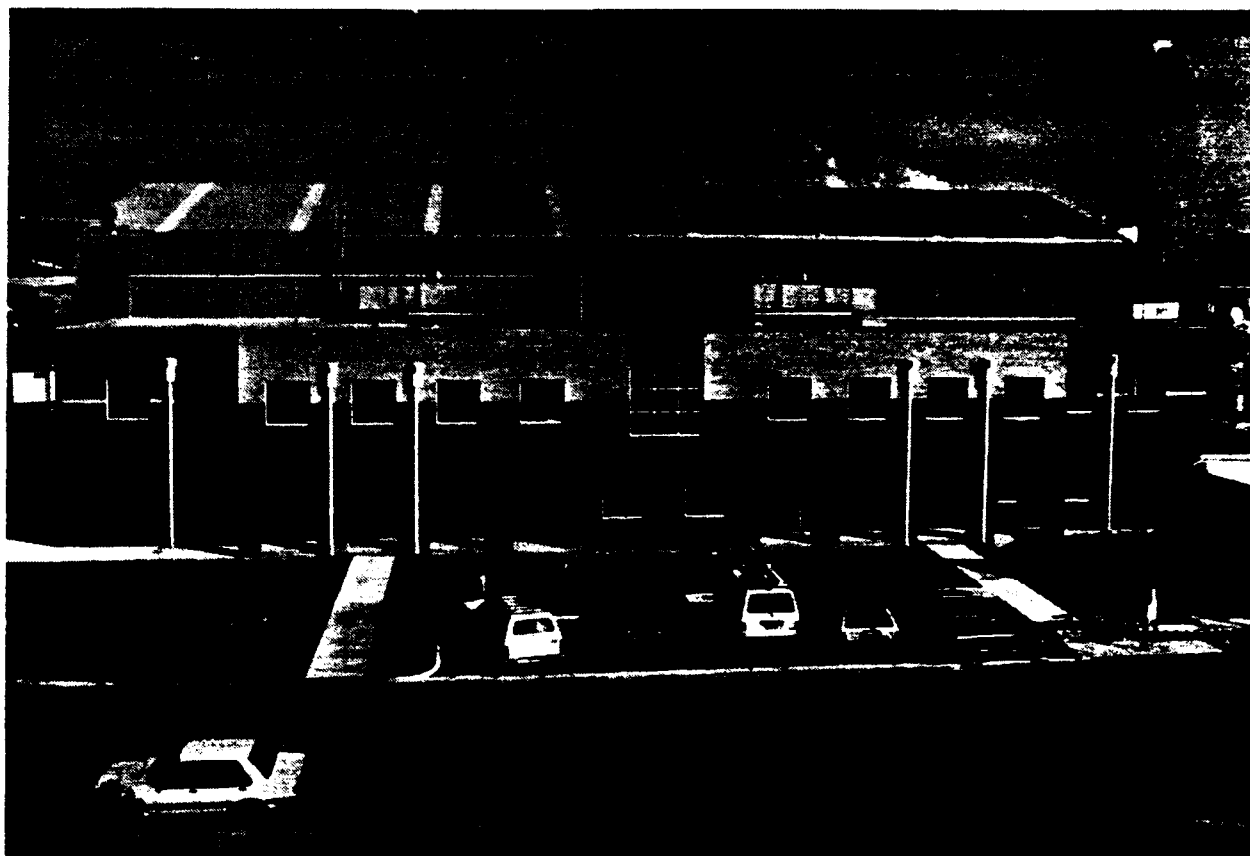


Fig. 1 Structural Test Laboratory

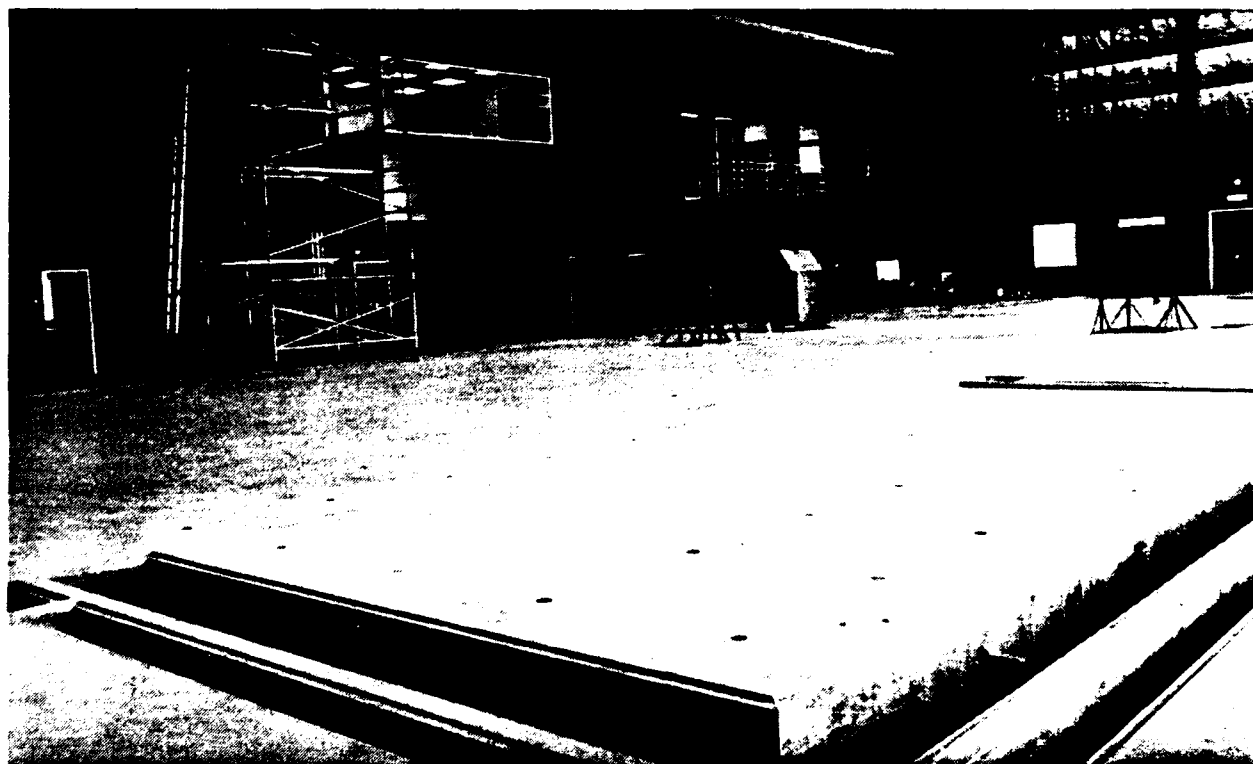


Fig. 2 Strong Floor



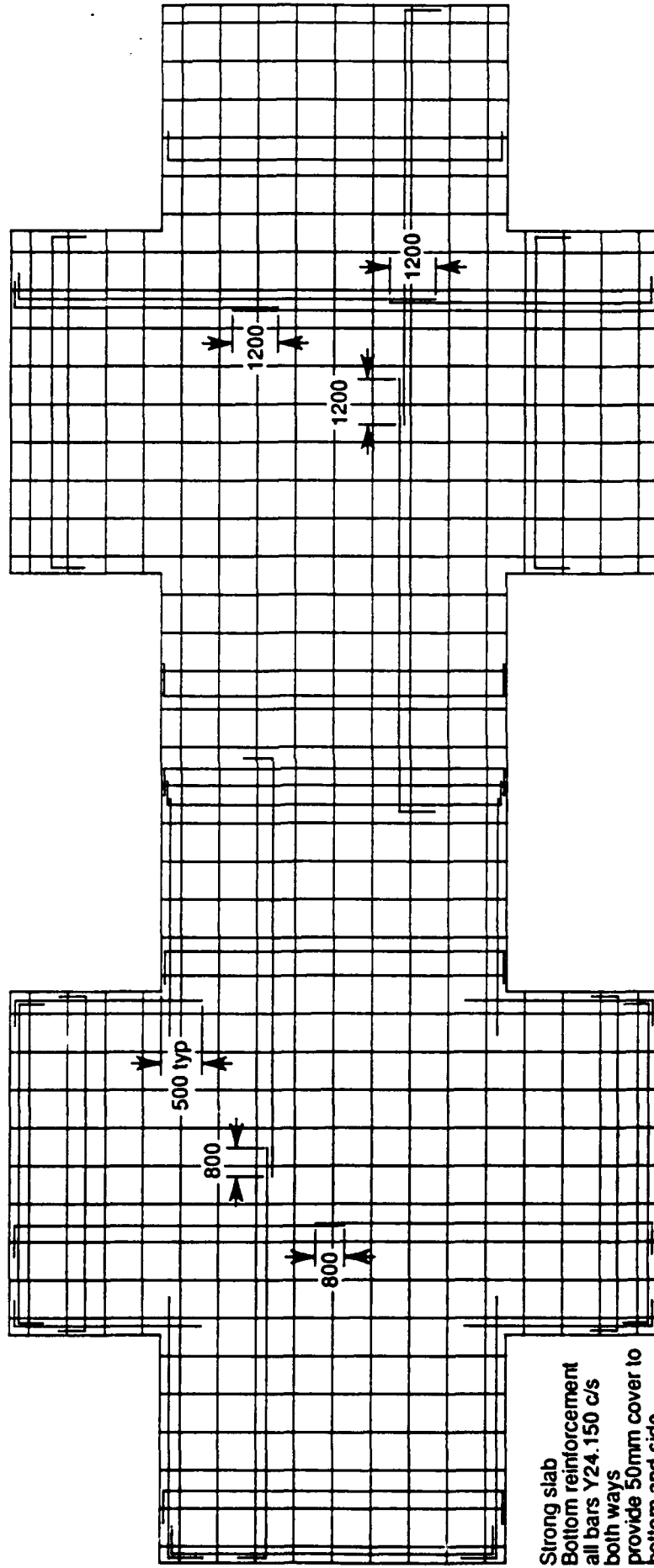
Fig. 3a Grid of Anchor plugs on a portion of the floor in the STL



Fig. 3b Close up of 4 anchors. One with a sealing plug removed



Fig. 3c Sub-floor view of anchors and reinforcement  
prior to concreting



Strong slab  
Bottom reinforcement  
all bars Y24.150 c/s  
both ways  
provide 50mm cover to  
bottom and side

Side face reo  
All bars Y20-200c/s horiz

Strong slab  
top reinforcement  
All bars Y24.150 both ways  
provide 30mm cover to top  
50 cover to side

FIG.4 FLOOR ANCHOR ARRANGEMENT

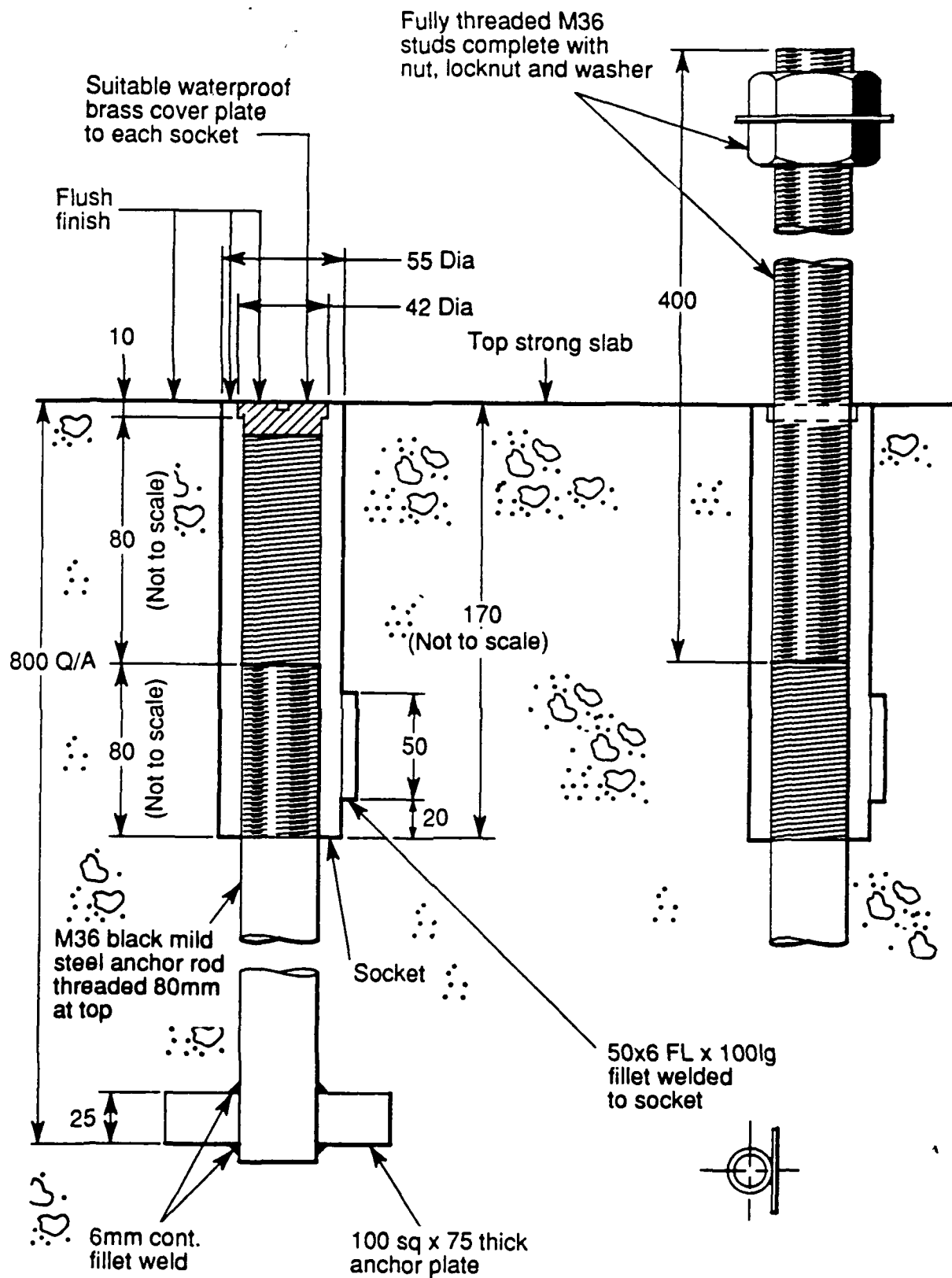


FIG.5 CAST-IN ANCHOR DETAILS

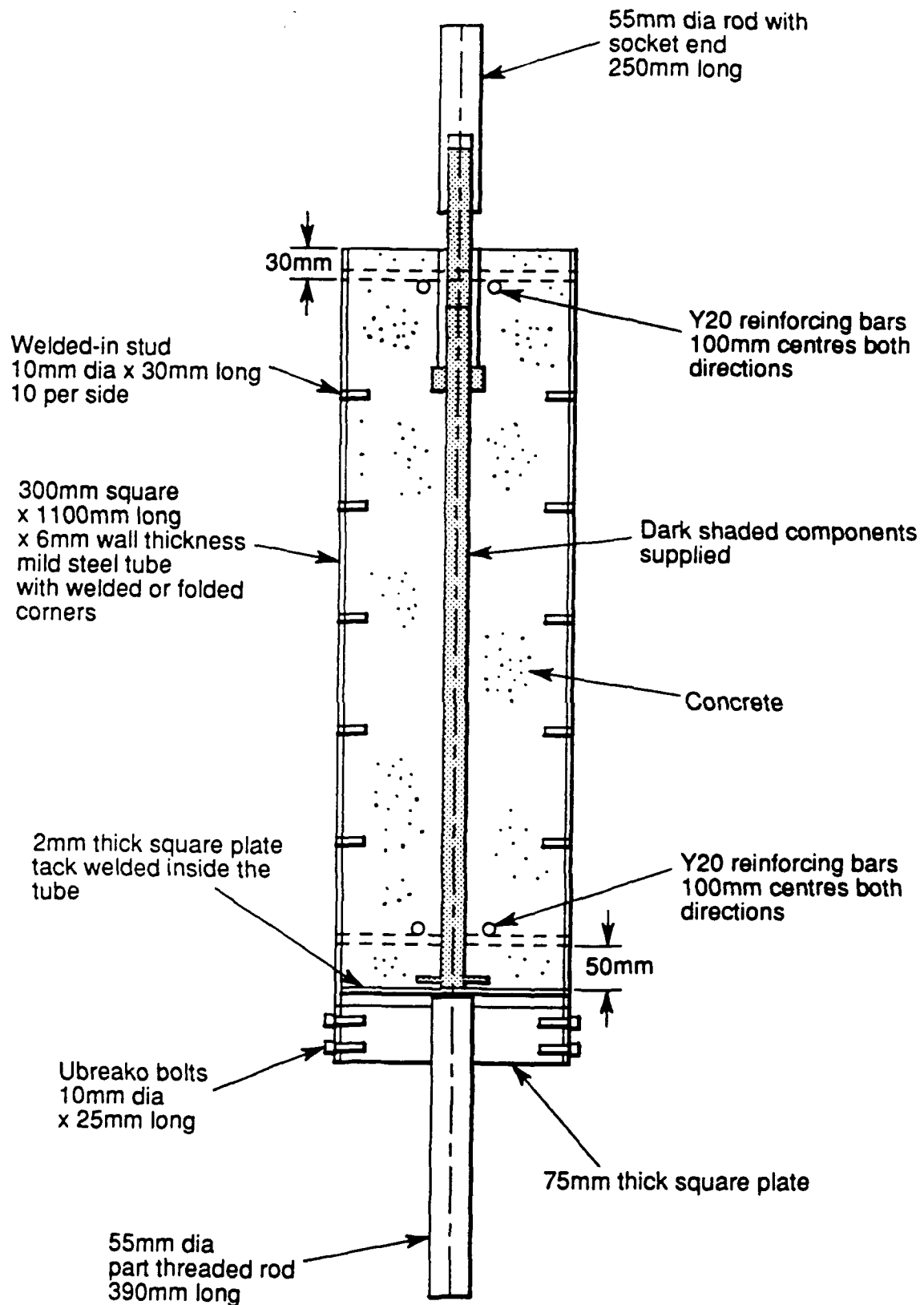


FIG.6 FLOOR ANCHOR SPECIMEN GENERAL ASSEMBLY.





Fig. 7 Casing of floor anchor specimen

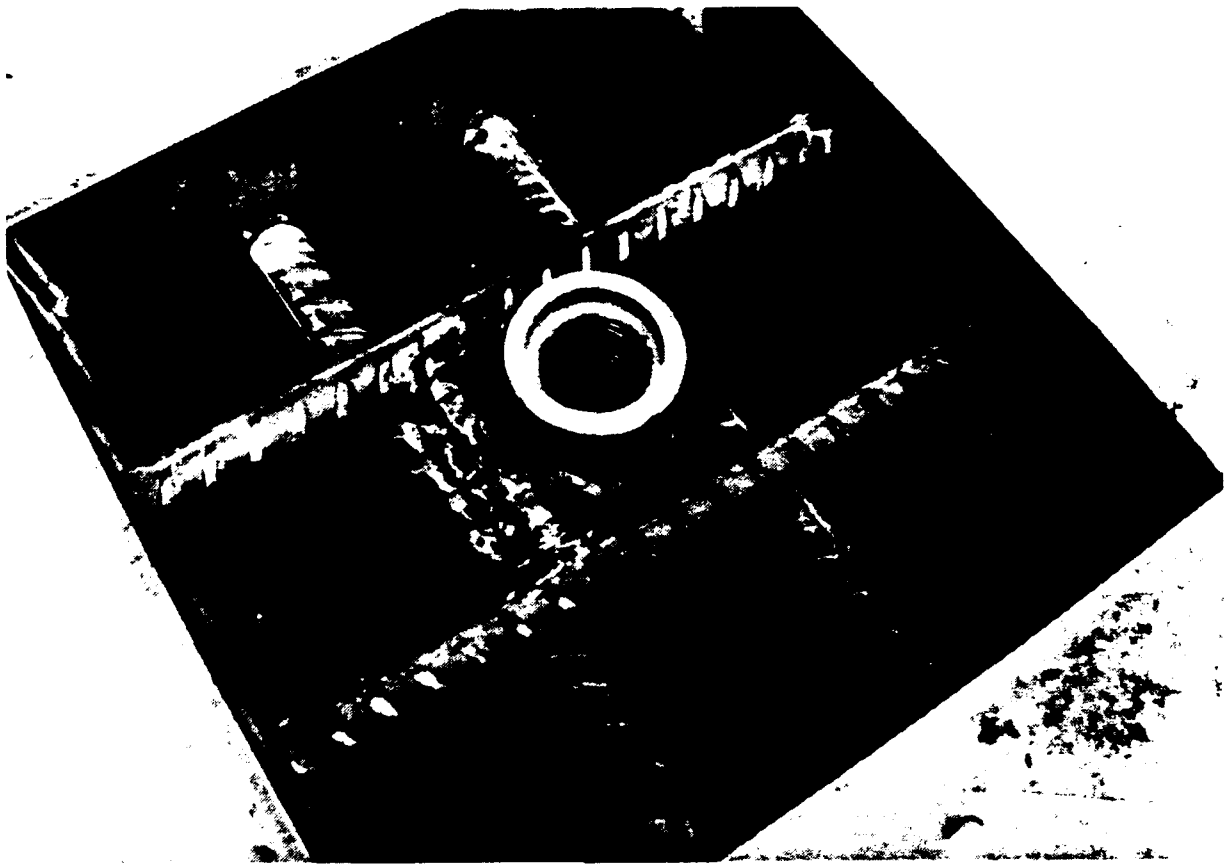


Fig. 8 View looking down on specimen before concrete is poured

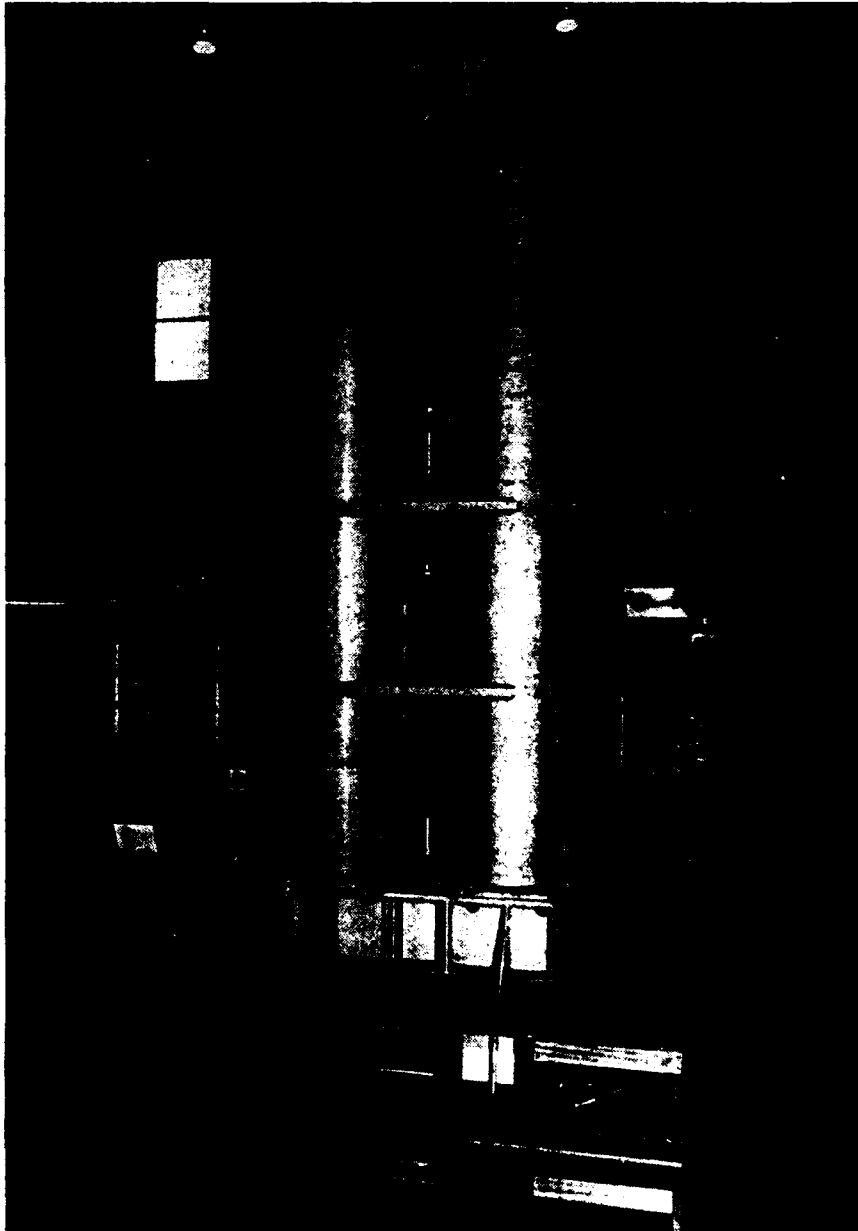


Fig. 9 General set-up in testing machine



Fig. 10 Close-up of specimen as mounted up against cross-head

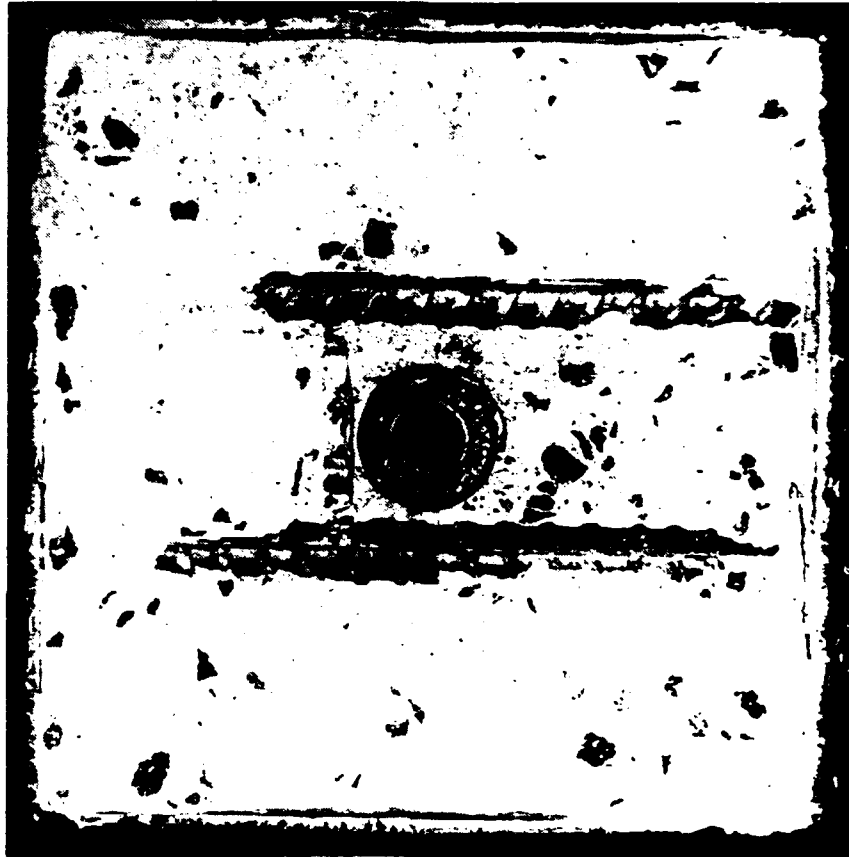


Fig. 11 Floor damage resulting from socket failure



Fig. 12a Stud fracture surface



Fig. 12b Anchor fracture surface

## APPENDIX A

### COMPARATIVE DATA

Data from References 1 and 2 are presented here for comparison.

Reference 1 has data on approximately 160 fatigue tests of solid steel bolts and studs with nominal thread diameter equal to or greater than 38 mm. Reference 2 has data on repeated tension fatigue tests carried out on prestressing tendons (32 mm diameter) and couplings.

Although these data are not for an assembly cast in concrete it nevertheless provides a guide to the fatigue life of such a specimen.

From [1]: Values for threads being cut or ground.

Failure at  $10^7$  (5 % scatter) occurred at 28.8 MPa alternating stress.

Mean stress for the range of specimens: 60.8 MPa to 281.2 MPa.

From [2]:

Failure at  $10^7$  cycles occurred at 20.7 MPa alternating stress.

Mean stress for the range of specimens: 414 MPa.

The 'cast-in' floor anchor did not fail after  $10^8$  cycles at 48.1 MPa alternating stress and a mean stress of 48.1 MPa.

### Fatigue life

The following is a fatigue calculation for the stud-socket arrangement without the influence of the surrounding concrete. The stresses are plotted on a fatigue diagram (fig. A1).

#### Data:

stud diameter of specimen = 36 mm

repeated load range = 0 to 98000 N (tension)

yield stress = 250 MPa (Mild Steel)

ultimate tensile strength (UTS) = 480 MPa (conservative)

endurance limit =  $0.5 \times \text{UTS}$  (typical)

=  $0.5 \times 480$

= 240 MPa

fatigue stress-concentration factor  $K_f = 3.8$  (for cut threads)

### Calculation:

The mean and alternating loads are:

$$P_m = \frac{P_{max} + P_{min}}{2} = \frac{98000}{2} = 49000 \text{ N}$$

$$P_a = \frac{P_{max} - P_{min}}{2} = \frac{98000}{2} = 49000 \text{ N}$$

$$\text{stress area} = 1018 \text{ mm}^2$$

Thus the mean and alternating stresses are:

$$\sigma_m = \frac{49000}{1018} = 48.1 \text{ MPa}$$

$$K\sigma_a = 3.8 \times \frac{49000}{1018} = 183 \text{ MPa}$$

A plot of the stresses (point A) shown in figure A1 indicates that the stud-socket arrangement is safe.

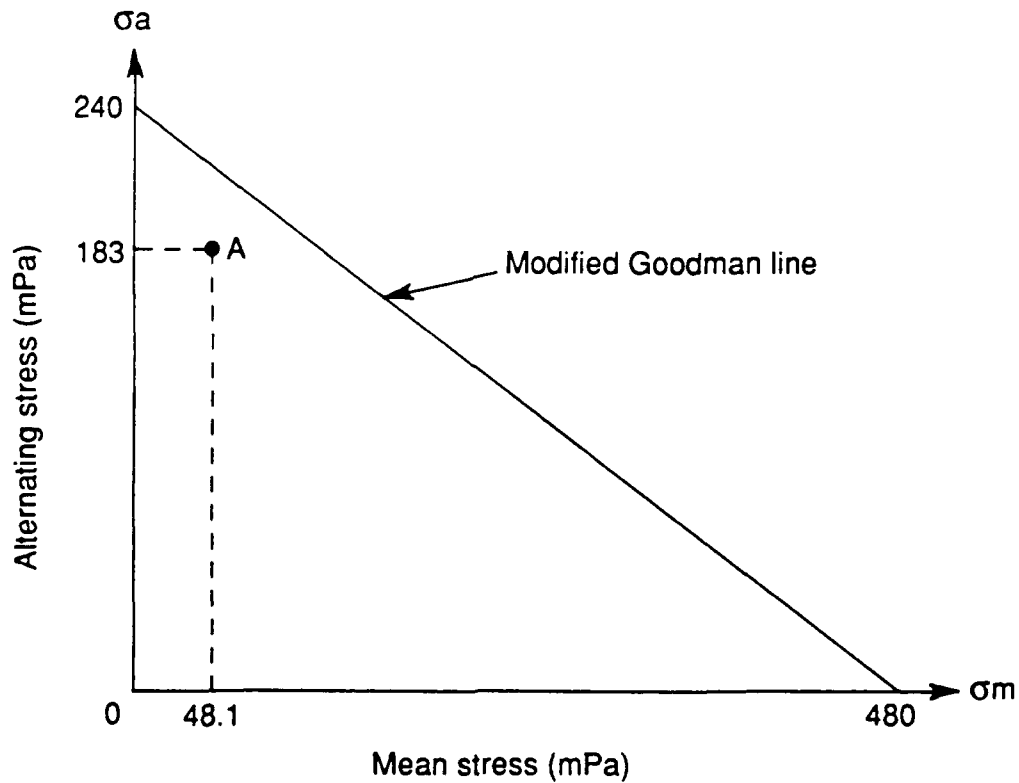


FIG.A1 FATIGUE DIAGRAM.



## APPENDIX B

### MACHINE COMPONENTS FOR FATIGUE TEST

#### Load cell properties.

manufacturer : BLH electronics  
type : U3G2  
serial No. : 83796  
capacity : 50.000 lb. (220 kN)

#### Actuator properties.

manufacturer : Vickers hydraulics  
Compact hydraulic (oil) cylinder.  
Model No. : V30-FC-NC-H-T-1R-5H

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